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Description

The present invention relates to a method of measuring alignment status by detecting changes in the position of a laser beam on a sensor unit fixed to a shaft line.

The invention also concerns a measurement apparatus of alignment status.

Alignment status refers to the actual position of the shafts of, for instance, concentrically mounted rotating machines after assembly and during use. The straightness of alignment is an essential factor particularly for the operation of large and rapidly rotating machinery. Such machines include turbine-generator machines of power plants, propulsion systems for ships with screw propeller drives, and different kinds of pump and blower machinery. Problems akin to the measurement of alignment status in rotating machinery are encountered in the deflection and vibration measurements of piping and evaporator equipment and in the deflection measurements performed during the loading and pressurization tests of different machines and pressure vessels.

In most cases the problem of missing measurements of alignment status has been experienced during the vibration measurements of the turbine machinery. The same problem is also encountered with pumps and blowers, because these machines are installed and aligned while at ambient temperature. In general, a sufficiently widely applicable measurement method capable of taking into account deflections caused by the heating of machinery has been lacking. Practical experience has, however, revealed that the relative displacements between the bearings as well as the bearings and their yokes cause substantial vibration problems generally invoked by the incorrect distribution of bearing loads between the individual bearings or by the friction of labyrinth ring seals and other types of seals. If it were possible to measure the changes in the alignment status during the running of the machinery in a reliable manner, the alignment could be adjusted to match the actual operating conditions to a higher degree, thereby allowing for a reduction of vibrations and wear in the machinery.

Measurement of the alignment of a shaft line is conventionally performed using, for instance, the following methods:

A "liquid level" developed by ENEL is based on the conventional principle known from levelling equipment. This equipment is intended for continuous monitoring.

The device has a complicated construction which is difficult to install and can't be moved. Further, the equipment is incapable of measuring movements in the horizontal plane. In regard to its operating principle, the system is inaccurate.

A laser-optical meter called "Permalign" is comprised of a laser and a beam detector. The laser is attached to either of the machines or bearing yokes and the detector cell is attached to the other. The device is applicable for continuous monitoring of two adjacently located bearings, while, however, unsuitable for the alignment status measurement of the entire shaft line in the turbine machinery. The equipment can only measure the relative displacements between any two points.

Disclosed in the publication WO 85/05443 is a measurement equipment for the relative displacement of two machines with concentric shaft lines. This equipment measures the displacements with the help of three measurement elements, which are comprised of a light source, a reflection prism and a beam detector. The light source and the beam detector are mounted on one of the machines, while the reflection prism is attached to the other machine. The displacements are measured by directing a light beam onto the prism which reflects the beam to a detector placed adjacent to the light source. The displacements of the machines in relation to each other can be computed from the displacement of the reflected beam. This method provides only for the measurement of the relative mutual displacement of two machines.

A measurement method based on the use of a laser is disclosed in US patent publication 3,902,810 featuring a capability of simultaneous alignment of several machines with concentric shafts during assembly. This method does not lend itself to the measurement of displacements during the running of the machinery.

DE-A-2,839,531 describes a system and method for measuring relative displacement in which fanshaped beams produced by a laser are projected in a plane to impinge on a pair of sensor units.

Thus, none of the commercially available measurement equipment is universally applicable to the alignment status monitoring of an entire turbomachinery outfit.

The present invention aims to achieve a method capable of continuous measurement of shaft line deviations of several machines with concentrically aligned shafts even during the running of the machines.

The invention is based on directing a fan-shaped laser beam onto a sensor element, the number of which can be one or greater, and then determining the relative displacement of each sensor element from the signals of the sensors.

According to one aspect of the invention, there is provided a method for measuring a change of alignment of the position of a laser beam on at least two sensor units, at least one of which sensor units is fixed in relation to a shaft line, charac-

terised in that at least one laser beam is expanded into a single, flat, fan-shaped beam by means of optical components, said flat, fan-shaped beam is directed onto at least two adjacent said sensor units so that said beam impinges simultaneously on the sensor elements of said at least two sensor units, the position of the laser beam on each said sensor element is determined at the start of a measurement session and the position value obtained is set as the zero reference point for each sensor unit, and the position of the laser beam on each sensor unit determined during the measurement session is compared with said zero reference point, whereby a representative value of relative displacement is obtained for each sensor unit.

According to a further aspect of the invention, there is provided an apparatus for measuring alignment status comprising at least one laser and a sensor unit assembly, characterised in that the laser incorporates a telescope and a lens, which elements serve for the expansion of the beam of the laser to form a horizontal fan beam, and the sensor unit assembly comprises at least two measurement sensor units onto which the fan-shaped beam of the laser can be directed simultaneously.

The invention offers significant benefits.

The apparatus facilitates the continuous measurement of displacements of the shaft line of several machines aligned with concentric shafts. In addition, the present method makes it possible to measure the displacements of pipelines and corresponding systems while they are running. Furthermore, the present method is applicable in vibration measurements. The method is accurate and provides in all conditions a precise indication of the relative displacement with respect to a reference point, or alternatively, by comparison of signals from adjacent sensors. Because the laser beam hits at least two sensors, the displacement or detachment of one of sensors or the laser unit is easily detectable. In addition to relative displacements, the present method provides the measurement of the absolute displacement of the measured points. Moreover, the apparatus necessary for the implementation of the method is easily portable as well as simple to install and use. The measurement computer of the system can be fed with 0...10 process variable channels (such as turbine elongations, power levels and temperatures), whereby changes in the alignment status can be compared with changes in the process status.

The invention is now described, by way of example, with reference to the accompanying drawings which illustrate an apparatus intended for the implementation of the method.

Figure 1 shows diagrammatically one of the measurement units from which the apparatus is constructed.

Figure 2 shows the apparatus diagrammatically in a top view from above the turbine machinery shaft line.

Figure 3 shows the apparatus diagrammatically in a side view behind the laser units.

In this exemplary embodiment, the measurement apparatus is adapted to a shaft line 16 between turbines 18,19 and 20 of a hydroelectric power plant and an electric generator 17. The laser units 1 are placed on triangular foundations on the turbine hall floor 23 behind a floor expansion joint 22 in relation to the turbines. A beam 4 emitted by the lasers 1 is directed at measurement sensors 10,11 placed on the bearing yokes 15 of the turbines 18,19 and 20 and the generator 17. The signals obtained from measurement sensors 10,11 allow for the indication of the position of the beam 4, while the relative displacement of the sensors is obtained through the subtraction of the readings provided by the sensors 10,11. Alternatively, the use of a reference sensor 21 allows for the detection of the displacement of the sensors 10,11 in relation to the reference sensor 21, thereby permitting the compensation of any possible displacement of the lasers 1.

An arrangement in which the measurement sensors 10,11 are placed at each coupling section of the shaft, while the reference is selected to be one of the sensors on the shaft line or a separate reference sensor 21, allows for the recording of the relative displacement of shaft line alignment between the turbines 18,19 and 20 during the running-up of a power plant, for instance. This procedure is carried out by measuring the change in the average position of the beam 4 for each sensor 10,11 in relation to the initial situation.

The measurement apparatus is composed of the units illustrated in Figure 1. A Helium-Neon laser 1 emits a visible beam of red light having a circular cross-section about 2 mm in diameter. The beam is directed through a telescope 2 and a cylindrical lens 3 in order to obtain a fan-shaped beam 4 which is flat in the horizontal plane. The beam 4 is aimed at one or several sensors 10,11 placed at a distance of, e.g., 5...10 m from the laser 1. from the laser 1. Due to the distance, the use of the telescope 2 is necessary to maintain the shape of the beam 4 as a sufficiently flat fan beam even at 10 m distance. The measurement sensor unit 10,11 comprises in the propagation direction of the beam 4 first a circularly polarizing filter plate 5, a He-Ne spectrum line filter 6, a CCD measurement sensor element 7 with its associated electronics 8, and a micrometer screw 9 for the height adjustment of the sensor section 10,11 of the sensor unit. Measurement data produced by the CCD sensor element 7 is transferred from the sensor unit 10 to a processor unit 12, which handles the

computations for each sensor pair 10,11. The computation programs in the PC microcomputer 14 and the process unit 12 operate in an integrated manner so that the PC 14 can query measurement information from several sensor units 10,11 through a data concentrator 13. The data concentrator 13 contains a power supply which provides operating voltages to the processor units 12 and further to sensor units 10,11. The measurement system can incorporate, for instance, 5 pcs. of processor units 12, whereby the total number of sensor units is 10 pcs.

The measurement sensors 10,11 are placed in pairs over bearing yokes 15 of a shaft 16. In this ways the fan-shaped beam of a single laser unit 1 will always impinge on the sensor elements of two sensor units 10,11 simultaneously. Such an arrangement ensures that the relative displacement between the sensors is measured in all conditions. By contrast, the use of a dedicated laser 1 for each of the sensors 10,11 would cause a measurement error of the relative displacement by errors in the determination of the positions of the lasers and by a possible displacement of the lasers during measurements. Furthermore, the fan-shaped form of the beam 4 enables a lower number of the lasers 1 to be used. The measurement sensors 10,11 are attached to the bearing yokes 15 by means of micrometer screws 9. The micrometer screws 9 make it possible to adjust the beam 4 of the laser 1 so that the beam impinges on a desired spot on the measurement sensor element 7 to comply with an estimated or measured displacement. The laser units 1 are placed on a tripod that rests on a steady foundation in a location which, in the exemplifying case, is behind an expansion joint 22 on the floor 23 of the machinery hall. By this method, the effect of machinery vibration on the operation of the lasers 1 is avoided and the alignment of the beam 4 is held steady, thereby allowing for the measurement of absolute displacements when desired.

The measurement of the shaft line 16 illustrated in the example is carried out as follows. First, the reference values for each sensor 10,11 are measured after the installation is completed and the turbine units 18,19,20 and before the generator 17 starts to rotate. The position of each bearing yoke is measured at a selected splitting plane, wherein one reference point per bearing is generally sufficient. These measured values are later taken as reference values for the measurements. Because the measured point is assigned the zero displacement reference point, the positions of the lasers 1 need not be measured, thereby relaxing the positional accuracy requirements during the installation of the laser 1, since the actual location of the zero reference point has no effect on the measured value which is the displacement from the zero point. The relative displacements are obtained as deviations from the zero point. One of the measured points can be selected as the reference point with respect to which the displacements of the other points are referenced, while alternatively the use of a separate reference sensor 21 is also possible. The reference sensor 16 can be fixed to any desired point; yet a location of the reference point between two sensors 10,11 so that the beam 4 of the laser 1 also hits the sensor element 7 of the reference sensor unit 21 makes the use of a separate laser 1 for the measurement of the reference point unnecessary. Through the use of the reference point, the effect of the displacement of the laser produces no error in the relative displacements.

As soon as the reference values and the reference point have been measured, the machinery can be started. Displacements of all points in relation to the reference point are monitored throughout the entire running-up cycle. When considered necessary, the monitoring function can be extended to cover the normal operation of the machinery. If excessive displacement of measured points is detected or the measurement indicates vibrations or tendency to vibration of the shaft line 16, the shaft line 16 must be realigned.

The measurement results can be printed in a desired manner. A convenient method is to display the relative displacement and measured process signals at constant intervals. The measurement results to be displayed are user-selectable in the system with user-definable scaling. The display of the system is continually updated with the progress of the measurement.

An alternative method is to display, for instance, the relative displacements in geometrical projection display of the monitored construction. The turbine sections are satisfactorily monitored by the display of displacements at the shaft, bearings and couplings.

In addition to the exemplifying embodiment described above, the method and apparatus in accordance with the invention can have alternative embodiments. Instead of the displacement measurements, the apparatus can be used for measuring vibrations by indicating the instantaneous position of the beam on the sensor element surface. Through the recording of the displacement and vibration signals during the run-up and run-down as well as normal operation, the correlation of the signals with simultaneously recorded process values becomes possible. In addition to the alignment of shaft lines in turbine and generator machinery, the apparatus is applicable to the alignment of pump and fan machinery as well as the displacement and vibration measurements of pipelines and

evaporators and further to the displacement and vibration measurements of machines and pressure vessels during their loading and pressurization tests.

An interesting application of the invention is in the alignment of screw propeller shafts of ships and boats, for instance, in order to measure the shaft alignment of long shafts of high rotational speed or of such small-diameter shafts that transmit high power. In these cases the shaft line can be provided with several sensors, and when the beam of the laser is expanded into an wide-fanned beam of appropriate shape, the beam of a single laser can be made to impinge on several sensors simultaneously, which the absolute straightness of the horizontally fanned beam allows for an accurate measurement of relative displacements of the sensors due to the exact horizontal plane position of the beam at each sensor.

Claims

1. A method for measuring a change of alignment of the position of a laser beam (4) on at least two sensor units (10,11) at least one of which sensor units (10,11) is fixed in relation to a shaft line (16),
characterised in that
at least one laser beam (4) is expanded into a single, flat, fan-shaped beam (4) by means of optical components (2,3),
said flat, fan-shaped beam (4) is directed onto at least two adjacent said sensor units (10,11) so that said beam (4) impinges simultaneously on the sensor elements (7) of said at least two sensor units (10,11), the position of the laser beam (4) on each said sensor element (7) is determined at the start of a measurement session and the position value obtained is set as the zero reference point for each sensor unit (10,11), and the position of the laser beam (4) on each sensor unit (10,11) determined during the measurement session is compared with said zero reference point, whereby a representative value of relative displacement is obtained for each sensor unit (10,11).

2. A measurement method in accordance with claim 1, characterised in that the measurement values from the sensor units (10,11) are routed to a data concentrator (13) for timing of the transfer of measurement data from the sensor units (10,11) to a computer (14) whereby the measurement values from the sensor units (10,11) can be read sequentially.

3. A measurement method as claimed in accordance with claim 2, wherein the measurement values for the sensor units (10,11) are routed to the data concentrator (13) via intermediate circuit components.

4. A measurement method in accordance with claim 1, characterised in that one of said sensor units (10,11) is selected as a reference sensor (21), whose measurement value is used as a reference value for the other sensor units (10,11).

5. A measurement method in accordance with claim 4, characterised in that the reference sensor (21) is a separate sensor unit placed outside the measured shaft line (16).

6. A measurement method in accordance with claim 1, characterised in that the fan-shaped beam (4) of each laser (1) is directed onto two measurement sensor units (10,11), whose measurement data is routed to a data concentrator (13) and further to a computer (14) in sequentially alternating manner from each sensor unit pair.

7. An apparatus for measuring alignment status comprising at least one laser (1) and a sensor unit assembly, characterised in that
   - the laser (1) incorporates a telescope (2) and a lens (3), which elements serve for the expansion of the beam of the laser (1) to form a horizontal fan beam (4), and
   - the sensor unit assembly comprises at least two measurement sensor units (10,11) onto which the fan-shaped beam (4) of the laser (1) can be directed simultaneously.

8. A measurement apparatus in accordance with claim 7, characterised by a data concentrator (13) through which a computer (14) can read the measurement value of each sensor (10,11) in a sequential manner.

9. A measurement apparatus in accordance with claim 7, characterised by a reference sensor (21) placed outside the measured shaft line to provide a measurement value relative to which the measurement values of the other sensor units (10,11) are compared.

10. A measurement apparatus in accordance with claim 7, characterised in that the sensor units (10,11) are arranged in pairs so that said fan-shaped laser beam (4) can hit each sensor unit pair (10,11) simultaneously.

Patentansprüche

1. Verfahren zur Messung einer Ausrichtungsänderung der Position eines Laserstrahls (4) an mindestens zwei Sensoreinheiten (10, 11), von denen mindestens eine gegenüber einer Wellenlinie (16) fest angebracht ist, dadurch gekennzeichnet, daß mindestens ein Laserstrahl (4) mittels optischer Bauteile (2, 3) zu einem einzelnen, flachen, fächerförmigen Strahl (4) aufgeweitet wird, der flache, fächerförmige Strahl (4) auf mindestens zwei benachbarte der Sensoreinheiten (10, 11) gerichtet ist, so daß der Strahl (4) auf die Sensorelemente (7) der mindestens zwei Sensoreinheiten (10, 11) gleichzeitig auftrifft, die Position des Laserstrahls (4) an jedem Sensorelement (7) zu Beginn eines Meßvorgangs bestimmt wird und der erhaltene Positionswert für jede Sensoreinheit (10, 11) als Nullreferenzpunkt gesetzt wird und die während des Meßvorgangs bestimmte Position des Laserstrahls (4) an jeder Sensoreinheit (10, 11) mit dem Nullreferenzpunkt verglichen wird, wodurch ein repräsentativer Wert der relativen Verschiebung für jede Sensoreinheit (10, 11) erhalten wird.

2. Meßverfahren nach Anspruch 1, dadurch gekennzeichnet, daß die Meßwerte von den Sensoreinheiten (10, 11) zu einem Datenkonzentrator (13) geleitet werden, um die Meßdatenübertragung von den Sensoreinheiten (10, 11) zu einem Computer (14) zeitlich zu steuern, wodurch die Meßwerte von den Sensoreinheiten (10, 11) sequentiell gelesen werden können.

3. Meßverfahren nach Anspruch 2, bei dem die Meßwerte für die Sensoreinheiten (10, 11) über Zwischenschaltungsbauelemente zum Datenkonzentrator (13) geleitet werden.

4. Meßverfahren nach Anspruch 1, dadurch gekennzeichnet, daß einer der Sensoreinheiten (10, 11) als Referenzsensor (21) ausgewählt wird, dessen Meßwert als Referenzwert für die anderen Sensoreinheiten (10, 11) verwendet wird.

5. Meßverfahren nach Anspruch 4, dadurch gekennzeichnet, daß es sich bei dem Referenzsensor (21) um eine außerhalb der gemessenen Wellenlinie (16) angebrachte separate Sensoreinheit handelt.

6. Meßverfahren nach Anspruch 1, dadurch gekennzeichnet, daß der fächerförmige Strahl (4) jedes Lasers (1) auf zwei Meßsensoreinheiten (10, 11) gerichtet ist, deren Meßdaten von jedem Sensoreinheitspaar abwechselnd auf sequentielle Weise zu einem Datenkonzentrator (13) und weiter zu einem Computer (14) geleitet werden.

7. Vorrichtung zur Messung des Ausrichtungszustands mit mindestens einem Laser (1) und einem Sensoreinheitsaufbau, dadurch gekennzeichnet, daß der Laser (1) ein Fernrohr (2) und eine Linse (3) aufweist, wobei diese Elemente der Aufweitung des Strahls des Lasers (1) zur Bildung eines horizontalen Fächerstrahls (4) dienen, und daß der Sensoreinheitsaufbau mindestens zwei Meßsensoreinheiten (10, 11) umfaßt, auf die der fächerförmige Strahl (4) des Lasers (1) gleichzeitig gerichtet werden kann.

8. Meßvorrichtung nach Anspruch 7, gekennzeichnet durch einen Datenkonzentrator (13), durch den ein Computer (14) die Meßdaten jedes Sensors (10, 11) auf sequentielle Weise lesen kann.

9. Meßvorrichtung nach Anspruch 7, gekennzeichnet durch einen Referenzsensor (21), der außerhalb der gemessenen Wellenlinie angebracht ist, um einen Meßwert zu liefern, auf den die Meßwerte der anderen Sensoreinheiten (10, 11) bezogen werden.

10. Meßvorrichtung nach Anspruch 7, dadurch gekennzeichnet, daß die Sensoreinheiten (10, 11) in Paaren angeordnet sind, so daß der fächerförmige Laserstrahl (4) jedes Sensoreinheitspaar (10, 11) gleichzeitig treffen kann.

Revendications

1. Méthode de mesure d'un changement d'alignement de la position d'un faisceau laser (4) sur au moins deux unités de détection (10, 11), l'une au moins de ces unités de détection (10, 11) étant fixe par rapport à une ligne d'arbres (16),
caractérisée en ce

qu'au moins un faisceau laser (4) est élargi en un faisceau (4) unique, plat, en forme d'éventail, au moyen de composants optiques (2, 3),

que ledit faisceau (4) plat en forme d'éventail est dirigé sur au moins deux unités adjacentes desdites unités de détection (10, 11) de sorte que ledit faisceau (4) frappe simultanément les éléments de détection (7) desdites au moins deux unités de détection (10, 11), la position du faisceau laser (4) sur chaque dit élément de détection (7) étant déterminée au

début d'une séance de mesure et la valeur de position obtenue étant fixée comme le point de référence zéro pour chaque unité de détection (10, 11), et la position du faisceau laser (4) sur chaque unité de détection (10, 11) déterminée lors de la séance de mesure étant comparée avec ledit point de référence zéro, une valeur représentative du déplacement relatif étant ainsi obtenue pour chaque unité de détection (10, 11).

2. Méthode de mesure selon la revendication 1, caractérisée en ce que les valeurs de mesure des unités de détection (10, 11) sont transmises à un concentrateur de données (13) pour la temporisation du transfert des données de mesure depuis les unités de détection (10, 11) vers un ordinateur (14), les valeurs de mesure des unités de détection (10, 11) pouvant ainsi être lues séquentiellement.

3. Méthode de mesure selon la revendication 2, dans laquelle les valeurs de mesure pour les unités de détection (10, 11) sont transmises au concentrateur de données (13) au moyen de composants de circuit intermédiaires.

4. Méthode de mesure selon la revendication 1, caractérisée en ce que l'une desdites unités de détection (10, 11) est sélectionnée en tant que détecteur de référence (21), dont la valeur de mesure est utilisée comme valeur de référence pour les autres unités de détection (10, 11).

5. Méthode de mesure selon la revendication 4, caractérisée en ce que le détecteur de référence (21) est une unité de détection séparée placée en dehors de la ligne (16) d'arbres mesurée.

6. Méthode de mesure selon la revendication 1, caractérisée en ce que le faisceau (4) en forme d'éventail de chaque laser (1) est dirigé vers deux unités de détection (10, 11) de mesure, dont les données de mesure sont transmises à un concentrateur de données (13) puis ensuite à un ordinateur (14) de manière alternée en séquence depuis chaque paire d'unités de détection.

7. Appareil de mesure de l'état d'alignement comprenant au moins un laser (1) et un ensemble d'unités de détection, caractérisé en ce que
   - le laser (1) comporte un télescope (2) et une lentille (3), ces éléments servant à l'expansion du faisceau du laser (1) pour former un faisceau (4) horizontal en éventail, et
   - l'ensemble d'unités de détection comprend au moins deux unités de détection (10, 11) de mesure sur lesquelles le faisceau (4) en forme d'éventail du laser (1) peut être dirigé simultanément.

8. Appareil de mesure selon la revendication 7, caractérisé par un concentrateur de données (13) au moyen duquel un ordinateur (14) peut lire la valeur de mesure de chaque détecteur (10, 11) de manière séquentielle.

9. Appareil de mesure selon la revendication 7, caractérisé par un détecteur de référence (21) placé en dehors de la ligne d'arbres mesurée pour fournir une valeur de mesure avec laquelle les valeurs de mesure des autres unités de détection (10, 11) sont comparées.

10. Appareil de mesure selon la revendication 7, caractérisé en ce que les unités de détection (10, 11) sont disposées par paires de sorte que ledit faisceau laser (4) en forme d'éventail puisse frapper chaque paire d'unités de détection (10, 11) simultanément.

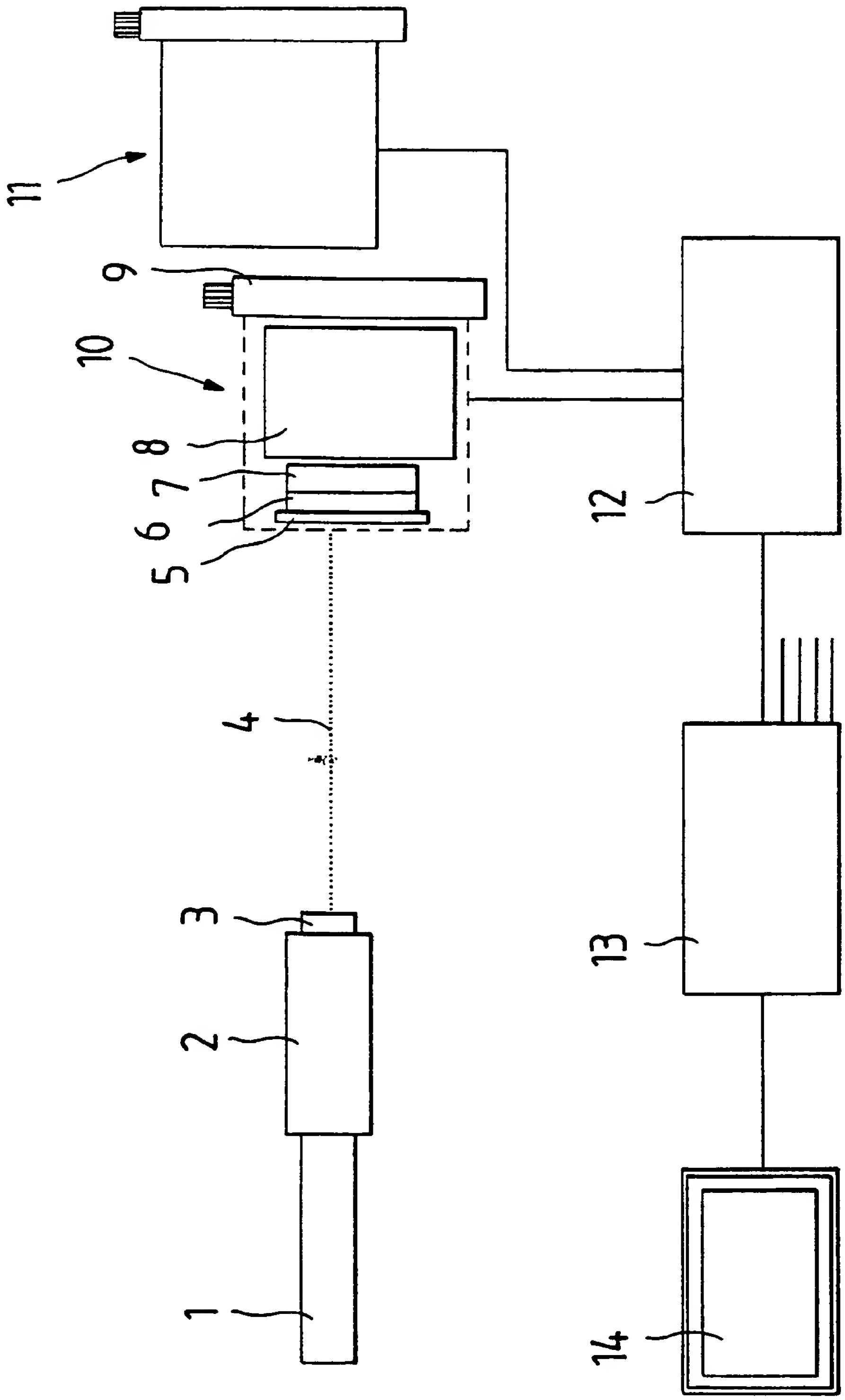

Fig.1

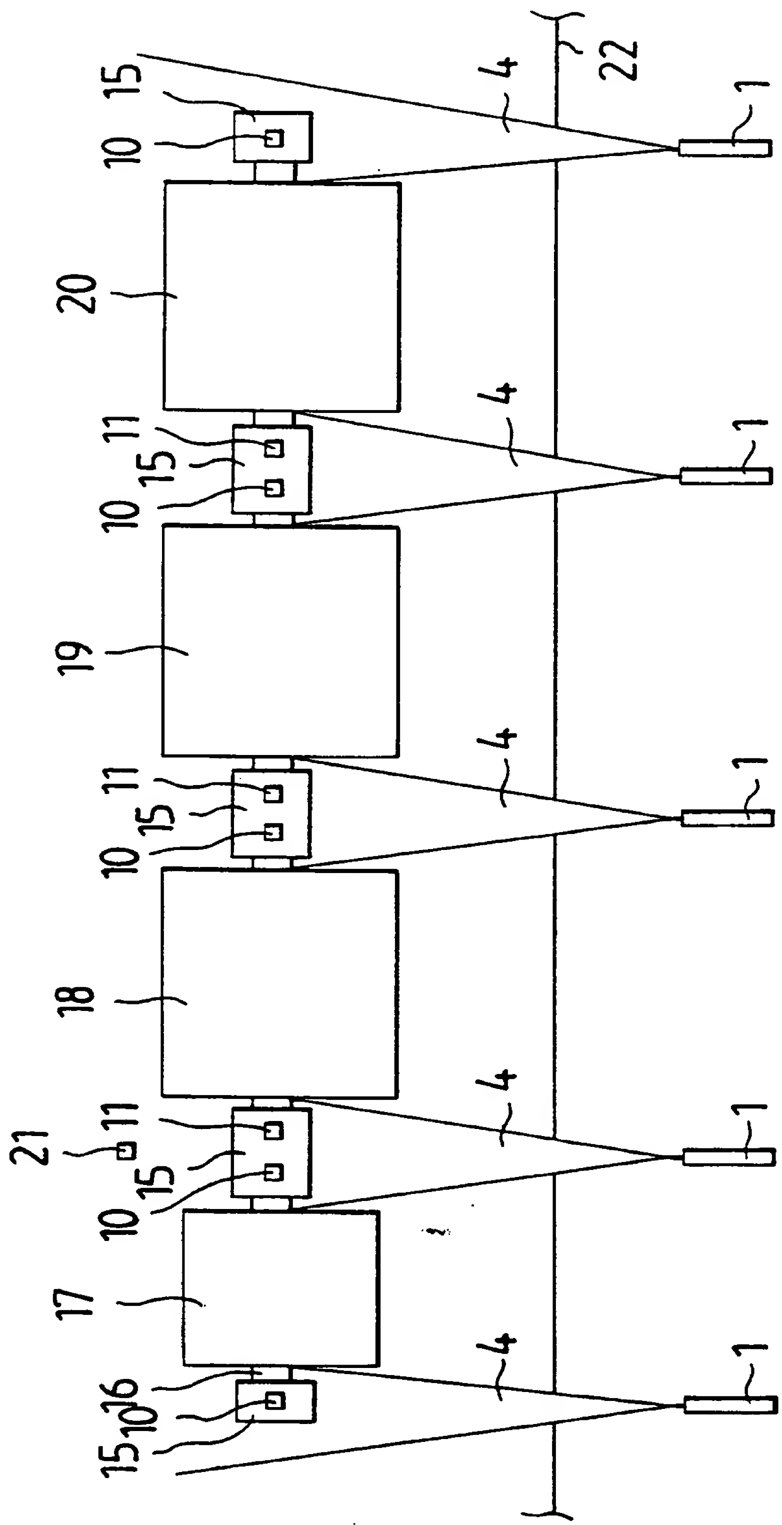

Fig. 2

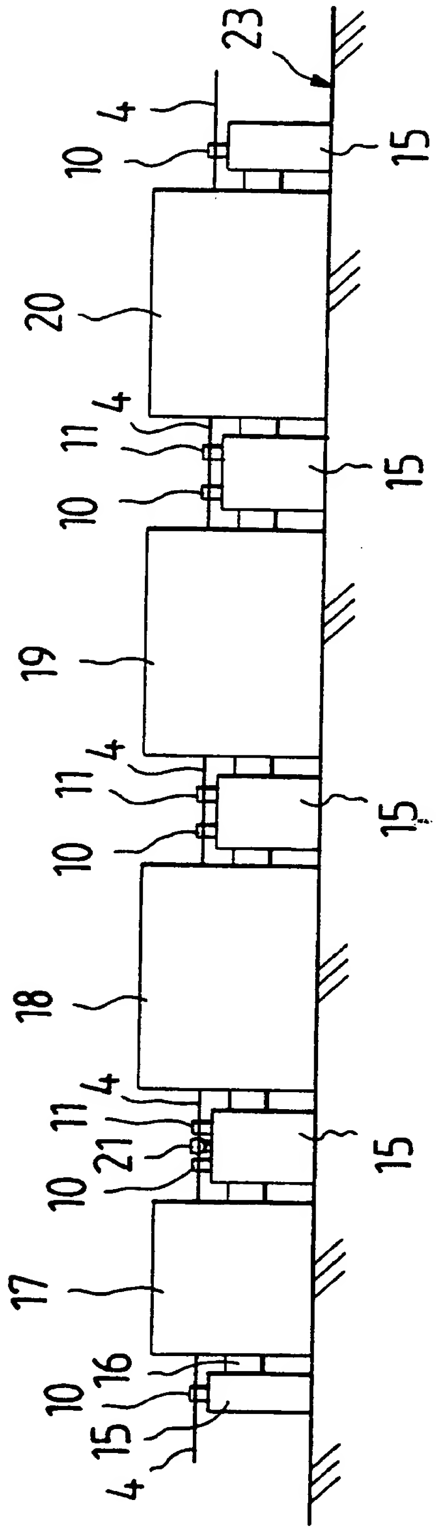

Fig.3